END
DATE
FILMED
2 83
DTIC

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

DTIC
A

OFFICE OF NAVAL RESEARCH

ONR PROJECT:

CENTER FOR RESEARCH ON ORGANIZATIONAL EFFICIENCY

ONR-N 00014-79-C-0685

Stanford University

PROGRESS REPORT: 1981-1982

April 1982

83 01 28   076

possibility of using existing results for societies with unidimensional policy spaces to understand ones with predictive elements.

T.R.   . (Reproduction in Process). David M. Kreps, Paul Milgrom, John Roberts and Robert Wilson, "Rational Cooperation in the Finitely-Repeated Prisoners' Dilemma," May 1982..

ABSTRACT

A common observation in experiments involving finite repetition of the prisoners' dilemma is that players do not always play the single-period dominant strategies ("finking"), but instead achieve some measure of cooperation. Yet finking at each stage is the only Nash equilibrium in the finitely--repeated game. We show here how incomplete information about one or both players' options, motivation or behavior can explain the observed cooperation. Specifically, we provide a bound on the number of rounds at which Fink may be played, when one player may possibly be committed to a "Tit-for-Tat" strategy.

W.P. 104. Robert Wilson, "Perfect Equilibria and Sequential Rationality," May 1982.

ABSTRACT

The Nash equilibr!· ·· a game do not discriminate between the normal and extensive forms. Among the Nash equilibria, therefore, some may be viable only if one or more players can initially commit to a strategy. An extensive game, however, includes in its description of the rules all possilbilities for commitment. The study of extensive games requires, therefore, that one restrict the Nash equilibria to those that do not presuppose commitments that

in fact are not feasible. Criteria that enforce this restriction can be called _perfectness_ criteria, following the original terminology of Reinhard Selten [1965].

The salient feature of perfectness criteria is a requirement that I shall call _sequential rationality_. Sequential rationality invokes the definition of optimality employed in dynamic programming. That is, a player's strategy is optimal only if, in each contingency in which a decision might be made, the prescribed choice is optimal in the remainder of the game with the players' subsequent strategies.

Several perfectness criteria have been embodied in proposed selections from the Nash equilibria:

1. _Subgame-perfect_ equilibria, Selten [1965];

2. _Sequential_ equilibria, Kreps-Wilson [1980];

3. _Perfect_ equilibria, Selten [1975];

4. _Proper_ equilibria, Myerson [1978].

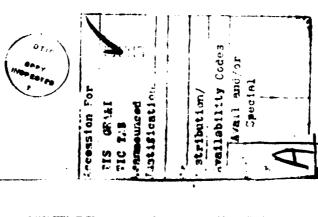These are listed in order of inclusion.

As Selten [1975] has pointed out, the latter two implement a further criterion that I shall call _robustness_. That is, besides being optimal in response to the other players' strategies, each player's strategy is also required to be optimal in response to some sequence of strategies assigning positive probabililty to every feasible choice.

In the sequel I will mostly review the definitions of sequential and perfect equilibria, and point out their close connections. I shall also discuss the problems of computation, and mention several recent applications.

The discussion is confined to finite games with perfect recall.

TABLE OF CONTENTS

STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305

CENTER FOR RESEARCH ON
ORGANIZATIONAL EFFICIENCY
Encina Commons

PROGRESS REPORT 1981-1982

TOPICAL SURVEY

1. INTRODUCTION

During 1981-1982 the work at the ONR Project Center for Research on
Organizational Efficiency has followed several different main lines of inves-
tigation. One series of studies has continued the Center's recent work apply-
ing to topics in organizational theory the methods of the theory of games with
incomplete information. A major theme of these studies is the crucial role of
information and timing in problems of decentralization and incentives. This
subject has been addressed in both problems of intertemporal cooperation, and
problems of competitive behavior in contexts of contracting and auctions. For
this year's survey, therefore, we describe the recent work on three topics
that represent the main issues involved.

The first topic on Rational Motives for Cooperation, reviews the role of
incomplete information in sustaining cooperative behavior in repeated plays of
the Prisoners' Dilemma game. The results indicate the sensitivity of much of
the extant work on cooperation (without enforcable contracts) to the very
strong common knowledge assumptions that are imposed.

The second topic, on Auctions and Bidding, reviews the dramatically
successful synthesis that was accomplished in the past year by Milgrom and
Weber. Their results, based on the theory of "affiliated" random variables,

unifies much of what had been known in the theory of auctions and competitive bidding, and obtains several major extensions. In particular, they are able to rank the various auction forms in terms of the expected profit to the seller.

The third topic, on Models of Reputation, reviews the accumulation of recent work on the role of reputations in explaining competitive behavior.

The line of work that comprises these three topics is only a part of the spectrum of the Center's activities. Brief descriptions of other major projects underway are described in the subsequent section on Other Research Activities.

2. RATIONAL MOTIVES FOR COOPERATION

In the past year a line of work at the Center has addressed one of the most perplexing problems at the heart of the theory of organizations. Paul Milgrom and Robert Wilson of the Center's staff, together with David Kreps and John Roberts, have studied the phenomenon of cooperation in situations where enforcable contracts are not feasible. The focus of this study is the well-known game called the Prisoners' Dilemma. Their joint paper, "Rational Cooperation in the Finitely Repeated Prisoners' Dilemma," will be published in a forthcoming symposium in the Journal of Economic Theory.

The Prisoners' Dilemma is the archetype of a wide class of situations in which cooperation is mutually advantageous for the participants but no individual has an incentive to cooperate. In its simplest version the game has two players and each player has two possible choices, either to cooperate (C) or not (N). Moreover, N is each player's preferred choice regardless of what the other player does, yet they are both better off if they both choose C. Assume that the players select their moves "simultaneously" in the sense that each chooses before he knows the choice made by the other player. In this game, by almost any criterion, the predicted moves are that both players choose N, and the resulting outcome is inferior to what they could have obtained by cooperating. This frustrating consequence of rational analysis of the game amply justifies the "dilemma" confronted by the players.

In many practical circumstances, however, such situations are actually part of a continuing relationship between the players. One could hope, therefore, that in the larger context cooperation would be forthcoming because of the greater possibilities for interaction; in particular, signalling and

punishment strategies become realistic possibilities. For example, one player could signal his intent to cooperate by playing C and then, if the other failed to play C also, punish him via one or more choices of N. Formally, this situation is studied in terms of the repeated game in which the one-stage Prisoners' Dilemma is repeated many times, and at each time each player knows the previous history of moves. For simplicity, assume that each player's payoff is just the sum of his payoffs in the sequence of stage games. Indeed, in the numerous experiments that have been done using this game most subjects do indeed succeed in achieving cooperation for most of the time. A principal objective of the work done at the Center is to provide a rigorous game-theoretic analysis of this empirical regularity.

The salient fact however, is that the repeated game has only one perfect Nash equilibrium, and this is the one in which each player always chooses not to cooperate. This result has a simple explanation. At the last stage, as we have seen, each player will surely choose N, so there is no advantage to choosing C in the next-to-last stage and each player will therefore choose N. Continuing in this fashion, the game unravels: at each stage, seeing no subsequent advantage to cooperative play, each player will choose N.

In our work at the Center we have focused on this apparent conflict between the empirical fact that subjects do cooperate often when playing this game, and the contrary prediction of the theory that cooperation is never part of an equilibrium strategy. Our thesis is that there is a fundamental defect in the theory--not in the mode of analysis, which is transparently correct, but in the original formulation of the game being played. We argue from the empirical evidence that subjects perceive the game in some way different from

the mathematical formulation assumed in the analysis. The crux of the matter is the presumption of the theory that subjects can and do analyze their personal situations using the backward induction argument invoked by the mathematical analysis. Presumably subjects perceive some long run advantage to cooperation, since there is surely no short run advantage, but this advantage is not recognized by the original formulation.

The weak link in the backward induction argument is the presumption that all of the data of the game is common knowledge between the participants. For example, in the one stage game it suffices that each player knows that N is his dominant strategy. But for the two stage game it is required that, say, player one knows also that player two knows that N is one's dominant strategy. In practice it is unrealistic to suppose that in a many stage game player one knows that player two knows that player one knows that...et cetera for a long sequence of "knows."

Our approach has therefore concentrated on reformulating the game to acknowledge that the players may lack common knowledge about all of the features of the situation assumed by the backward induction argument in the standard game-theoretic analysis. Indeed, the main conclusion reported in the paper is that a very slight uncertainty on the part of either player is sufficient to induce cooperative behavior as a Nash equilibrium for all but a few stages of the game.

Here we shall describe briefly one instance of this general conclusion. Suppose that the following is common knowledge: player one is a standard payoff-maximizing player but there is a small probability that player two is not, and player two knows whether he is in truth payoff-maximizing or not. If

he is not, we shall assume he is one who plays the tit-for-tat strategy, namely, he will begin by cooperating (C) but he will respond to a move of N by player one at any stage by choosing N at the next stage, and similarly he will respond to C by choosing C at the next stage. In this case we can establish that in a perfect Nash equilibrium both players will play cooperatively for all but a fixed number of stages that is independent of how many stages there are. The logic of this result is quite complex but we will sketch a few aspects.

First, if two ever fails to follow the tit-for-tat strategy then one will realize that he is a payoff-maximizing player and thereafter both will play noncooperatively, as we saw previously. Consequently, even if he is payoff-maximizing two's best option (with some provisos) is to imitate a tit-for-tat strategy if sufficiently many stages remain that the long run benefits outweigh the short run. Therefore, with two playing tit-for-tat, one's best option is also to play cooperatively. The result is that both play cooperatively, regardless of two's type, for all but a limited number of stages. (Some technical arguments are needed to verify the foregoing sequence of statements, and to establish that the maximum number of noncooperative episodes is bounded independently of the length of the game.)

The essential features that drive the analysis of this example are valid in a much wider context. The basic idea is that the backward induction argument is invalid when the participants are not on the same informational footing. Moreover, even a slight chance that one player is inclined to cooperate gives him the possibility of "imitating" this behavior, and if he does so both

gain because it is now in the best interests of each to sustain a long sequence of cooperative moves.

This is, we believe, the first instance that cooperative play has been justified in terms of optimizing behavior in the finitely repeated Prisoners' Dilemma, in spite of the overwhelming evidence that it is descriptive of actual behavior in experimental settings. We hope that this new approach developed at the Center will open new perspectives on the fundamenta ablems of incentives for mutually beneficial cooperation.

Lastly, it is worth mentioning that our approach to this pro is an outgrowth of our earlier work on the theory of predation, such as _ :datory pricing, entry deterrence, and wars of attrition. In both cases, the key ingredient has been the recognition that the missing ingredient in the naive formulation was the role of incomplete information. The theory of dynamic games with incomplete information has been a powerful tool to resolve long-standing discrepancies between observational evidence and the predictions of the theory. We anticipate that the further development of this theory and its applications will continue to provide new insights into multi-person decision problems--because it dispenses with the restrictive assumption of common knowledge which so often has restricted the realism and applicability of game theory to practical problems.

3. AUCTIONS AND BIDDING

The theory of auctions and bidding strategies is a continuing area of research at the Center. During the past year two main projects were completed. One is the comprehensive comparative study of various auction forms authored by Paul Milgrom of the Center staff and his co-author Robert Weber: "A Theory of Auctions and Competitive Bidding." The second is a study (not yet published in Technical Report form) by Robert Wilson of the Center staff: "Equilibria of Double Auctions." Double auctions are market games in which both buyers and sellers submit bids. In both of these studies the methods of the theory of games with incomplete information are used to study auctions in which each participant has private information about the valuations he places on the items traded. The study of auctions with private information dispersed among the participants is of central importance to the theory of bargaining generally and in particular to the analysis of price determination in contracting and procurement. In this survey we will review only the main accomplishments of the past year, although they are only the latest in a series of contributions to this subject by the Center.

A. One-Sided Auctions

The recent work by Milgrom and Weber concentrates on auctions in which buyers bid for a single item offered by a seller. This work has two components. One has been the development and application of the theory of "affiliated" random variables in order to extend and unify the theory of bidding processes. The second has been the comparative analysis of the several different forms of auctions commonly found in practice.

The technical definition of affiliation embodies the following feature. A set of random variables are said to be affiliated if, roughly speaking, large values for some of them make it more likely that the other variables in the set also have large values. In the appendix to their paper they present a fairly complete development of the theory of affiliated random variables for the study of bidding processes, including several new results. This theoretical substructure enables a very simple, and at the same time, very general treatment of the principal formulations of auctions as games with incomplete information. In most cases the salient feature of the statistical dependence among the random variables appearing in a formulation is that they are affiliated in the sense mentioned above. For example, if several buyers are bidding for an item of unknown value about which each buyer has acquired a privately known estimate, then it is usual to suppose that the estimates are all positively correlated with the true value and with each other. The general way in which to describe this sort of mutual positive association is to say that the set consisting of the value and the estimates is an affiliated set of random variables.

Applying the theory of affiliated sets of random variables to the comparative study of auction forms, Milgrom and Weber are able to obtain clear-cut characterizations of the relationships, in terms of the seller's expected revenue, among the following types of auctions:

1. the English or oral auction, with ascending oral bids;

2. the Vickrey or second-price sealed-bid auction in which the high bidder pays the second-highest bid;

3. the first-price sealed-bid auction;

4. the Dutch auction, with descending price until some buyer

    claims it at that price.

In each of these auction formats it is assumed that the bidders' privately assessed valuations and the underlying true value of the item form an affiliated set of random variables. The main results are obtained for the case in which the buyers are not risk averse.

A first result is that quite generally the Dutch and first-price auctions are entirely equivalent: they are strategically equivalent for the buyers and they yield the same expected revenue for the seller. The second result, of great practical importance for the choice among auction forms, is that in terms of the seller's expected revenue the best is the English auction, followed by the second-price or Vickrey auction, and lastly, the Dutch and first-price auctions. It is significant that they are also able to establish that this ranking is unaltered if the seller is also able to impose optimal entry fees and a reserve price that sets a floor on the allowable bids. Furthermore, the English auction remains superior to the Vickrey auction even if the buyers have constant absolute risk aversion (the comparison between the first and second-price auctions is ambiguous when there is risk aversion).

An additional topic investigated in their work is the seller's optimal strategy of disclosure when he has private information. For example, besides full and honest disclosure, the seller might conceal, censor, summarize, or obfuscate (by adding noise). The chief result in every auction is quite simple: honesty is the best policy.

A variety of additional topics are investigated as well. For example, in a wide class of situations a buyer with inferior information can at best obtain an expected profit of zero.

Besides obtaining the long-sought comparison among the major auction designs when buyers' informations are statistically dependent, an important accomplishment of the work done by Milgrom and Weber is the unifying theoretical treatment it provides. There are now much brighter prospects that complicated issues that arise in much more complex models can be addressed successfully. For example, in subsequent studies there is the prospect that multiple simultaneous auctions, for single or multiple items in each, or repeated auctions will succumb to analysis by similar methods.

B. Double Auctions

The project undertaken by Robert Wilson is an analysis of the efficiency of double auctions, and a characterization of the buyers' and sellers' optimal strategies for submitting bids and offers. In the model studied, each participant (buyer or seller) wants to trade (buy or sell) one unit of a homogenous commodity at a price more favorable than his privately known reservation price. It is assumed that there are no income effects and no risk aversion. Also, each trader's reservation price is drawn independently from the same probability distribution (depending on his type: buyer or seller).

The central issue addressed in this study is the characterization of efficient mechanisms of exchange. That is, given that each participant's reservation price is his private information, and therefore his trading strategy need not accurately reveal his valuation of items, which kinds of trading

rules induce a game of incomplete information in which the participants' equilibrium strategies yield an efficient outcome?

The trading rules for a double auction imitate the trading rules for a wide class of market mechanisms found in practice. The buyers and sellers submit sealed bids and offers; these are then aggregated into a demand curve and a supply curve that are intersected to find a range of market clearing prices (the midpoint of the interval of clearing prices is used in the present version); all trades are then made between buyers offering higher bids and sellers making lower offers.

The chief result is the demonstration that a double auction is indeed an efficient mechanism in the sense that among all possible trading rules a double auction maximizes the expected aggregate surplus of the buyers and sellers combined.

An outgrowth of this work is the prospect that the theoretical results obtained can be used to analyze the striking experimental results that have been found in studies by Vernon Smith and Charles Plott. (The experiments have been conducted using oral double auctions, in which participants submit their bids and offers publicly and sequentially, but many of Wilson's results carry over; in any case new experiments using sealed-bid double auctions are contemplated.) In these studies a remarkably high percentage of the auctions achieve an efficient allocation and there is very quick convergence to a Walrasian market-clearing price.

The conclusion that double auctions are efficient also has a basic importance for the foundations of the economic theory of markets. Traditionally, much of economic theory has been built on the assumption of perfect

markets, devoid of private information, in which participants respond to prices passively but do not actively set prices. In contrast, in a double auction as formulated above each participant knows only his own reservation price and acts consciously to name a bid or offer that he knows may influence the final price that will clear the market. We hope that further studies in this direction will substantiate to what degree the traditional economic models apply to exchange processes in which participants have private information and there are sufficiently few on either side of the market to influence prices. More generally there is the prospect that one can build a constructive theory of the design of incentive-efficient mechanisms for exchange and other organizational resource allocation processes.

4. MODELS OF REPUTATION

In the preceeding discussion on the Rational Motives for Cooperation we mentioned that in the Prisoners' Dilemma game one feature that is sufficient to induce cooperative play in most repetitions of the game is a slight chance that one of the players might be committed to using the tit-for-tat strategy. This remarkable result is actually an example of a more general phenomenon. In a wide class of situations involving sequences of choices over time, a slight degree of incompleteness in some player's information is sufficient to induce drastic changes in the qualitative character of the equilibrium strategies. The early work on this phenomenon was reported by David Kreps and Robert Wilson of the Center staff in their study of the repeated game called the Chain Store Paradox. A survey of portions of their work was described in last year's Progress Report; their Technical Report is now to be published in a forthcoming symposium in the Journal of Economic Theory. Also in the symposium will be a companion article (recently published as a Technical Report of the Center) on the same theme by Paul Milgrom of the Center staff and his co-author John Roberts. The joint work of these four authors has now developed into a major line of investigation in which the role of reputation effects in dynamic multi-person decision problems is the principal subject.

In their work Milgrom and Roberts use the Chain Store Paradox game as a central example in which to develop formally the theory of reputations. In principle a player's reputation is simply the probability distribution that other players assign to his possible preferences or modes of behavior. For example, a player might be either rational (i.e., utility maximizing) or irrational. In such a case the player's reputation is represented by the

probability assessed by others that he might be irrational (or equally well by the complementary probability that he might be rational). Thus in the repeated Prisoners' Dilemma game the possibility of irrationality is that the player might adhere firmly to the tit-for-tat strategy, and the probability of this possibility constitutes the player's reputation.

The sequencing of moves over time introduces into a game a new feature that is the focus of the theoretical studies of reputation effects. A player's reputation may be a valuable asset that he will want to maintain or enhance. The value of a favorable reputation lies in the fact that it reflects his opponents' ignorance about his actual motivations or subsequent behavior. For example, if the possibility of irrational behavior has sufficiently high probability then it may deter opponents from taking aggressive actions. Moreover, there is in addition the striking consequence that the player, even if he is actually rational, may have an induced incentive to adopt or imitate seemingly irrational behavior if it is not excessively costly in the short run and in the long run it sustains his opponents' ignorance about his motivations or predictable behavior in subsequent encounters.

One important additional feature in Milgrom and Roberts' analysis of reputation effects is their demonstration that the phenomenon derives essentially from a lack of common knowledge among the players as to exactly which game it is that they are playing. In one of their examples all of the players know that each player is "rational" but this fact is not common knowledge. That is, player 1 knows that player 2 is "rational," but player 2 is uncertain whether player 1 knows this. From this kind of example we have learned the important role that is played by assumptions of common knowledge in a wide variety of economic modeling and analysis.

It is worth mentioning that the central analytical tool in this body of work is the concept of a sequential equilibrium, developed in the work of David Kreps and Robert Wilson that was described in last year's Progress Report. Their paper will appear in a forthcoming issue of Econometrica.

Reputational effects were also a major topic of discussion at the conference on theories of industrial organization that was held at Stanford in January and partially sponsored by the Center.

5. GENERAL THEORY OF NON-ZERO-SUM REPEATED GAMES
WITH INCOMPLETE INFORMATION

The topics reported on in the sections on "Rational Motives for Coopera-
tion," and "Models of Reputation," are special cases of non-zero-sum repeated
games with incomplete information. They involve a repetition of a similar
game situation in which, however, some underlying and permanent facts are
known to one player but not to others. A general characterization of all
possible solutions (equilibrium points) to such games has not hitherto been
available. It has been obtained for the case of two players by Sergiu Hart.

The problem has the following essential difficulty. Consider the
"informed" persons. It is clearly desirable to use their information to
improve their outcome; but if they use it, they may reveal it to the other
persons, and their advantage vanishes. The uninformed also have a dilemma;
the informed may take actions which are intended to deceive others.

Consider two individuals, one of whom has inside information whether or
not a company has developed a new product. Suppose the innovation has
occurred. Should he purchase stock on the market? If he does, then the
uninformed will see this, deduce that the innovation has occurred, and buy
shares. The price will rise, preventing the informed person from buying more
than a few shares at a low price. On the other hand, the uninformed individ-
ual, who observes the informed individual buying stock, cannot be entirely
sure of its meaning. For if the innovation did not occur, the informed indi-
vidual may buy stock to spread the belief in the innovation and then sell out
at a high price.

If the game situation is repeated, there is time for what is in effect signalling among the players; that is, one player's actions in one play of the game yield information to other players for use in subsequent plays.

In the case of repeated games with complete information, there is a well-known result, known as the Folk Theorem since its authorship is uncertain; any outcome that is feasible and individually rational (i.e., yields a payoff to each player which is at least as good to him/her as the player can guarantee by suitable choice of strategy) can be achieved as an equilibrium point of the repeated game.

Sergiu Hart has obtained a complete characterization of all equilibria in repeated games of incomplete information with two players. Every equilibrium is equivalent to a collection of non-revealing "plans," of which one is chosen at random. The choice is made by a sequence of communications of two types: signalling (implicit transmission of information) and jointly controlled randomizations (lotteries in which neither player can unilaterally change the probabilities). With the equilibrium strategies so defined, it will not pay either player to change in any way (reveal more or less, double-cross on moves within any single play, and so on). Each player is prepared to undertake "punishing" strategies if the other deviates from the "master plan," just as in the complete information case. Asymptotically, all the information that is ever going to be revealed is revealed; the differences in information that remain are never going to be used, because the possessor of the differential information will reveal it by using it.

OTHER RESEARCH ACTIVITIES

KENNETH J. ARROW

Kenneth J. Arrow has been working on several projects. One is the beginning of an attempt to introduce the "irrational" elements of human decision-making recently stressed by cognitive psychologists into descriptive and normative economic analysis. In Technical Report 351, "Risk Perception in Psychology and Economics," (now published in Economic Inquiry 20 [1982]: 1-9), he pointed out that empirical observations of excess volatility in the stock and bond markets were consistent with the representativeness heuristic of individual cognition found experimentally by Amos Tversky and Daniel Kahneman. He is now considering the normative implications of similar violations of the usual axioms of rational choice with regard to decisions about collective risk-bearing (e.g., uncertainties in defense expenditures and capabilities, environmental regulation). He is also completing a survey of the effects of differential information on the workings of competitive markets and continuing some earlier research on economies of scale associated with the acquisition of information.

ROBERT J. AUMANN

Robert Aumann's research during his visit at the Center last year was described in detail in last year's progress report. His work included three main lines of investigation: equilibria of repeated games with incomplete information; purification of mixed strategies; and interpretation of arbitration procedures (some of ancient vintage from the Talmud) as values of cooperative games in which the "power" of a coalition is reinterpreted as its

"rights." Of these, the results of the first topic are substantially included in the major new technical report by Sergiu Hart, "Non-Zero-Sum Two-Person Repeated Games with Incomplete Information" (T. R. 367). In particular, Aumann and Hart have worked on the mathematics of the stochastic processes underlying Hart's paper. They introduce a new type of stochastic process, the bi-martingale: Let (a_n, p_n) be a martingale where, at each stage n, precisely one of the two components changes and the other remains unchanged. Bi-martingales occur naturally in the theory of repeated games with incomplete information.

The second has since been published (with an unfortunate omission of the ONR acknowledgement), and the third is presently mainly represented by the Notes that Aumann prepared for his seminar presentation in August.

PETER J. COUGHLIN

Peter Coughlin, formerly of the Center's staff and currently a post-doctoral fellow at Carnegie-Mellon University, completed, in collaboration with Melvin Hinich, a study begun at the Center, "Necessary and Sufficient Conditions for Single-Peakedness Along a Linearly Ordered Set of Policy Alternatives," (T.R. reproduction in process). Each voter first predicts each candidate's policy position (a vector in a finite-dimensional space) from an ordered set of predictive elements (e.g., location on an ideological continuum; different voters may have different predictive relations. There is an ordering on the policy space for each voter; together with the voter's predictive map, this defines an induced ordering on the predictive elements. The question raised is under what conditions on the predictive map is the ordering

of the predictive elements single-peaked for every convex ordering on policy space. A necessary and sufficient condition is given.

WILLIAM M. GORMAN

William Gorman, of Oxford University, spent a short period at the Center a year ago and completed two manuscripts, one of which has been completed as Technical Report No. 359, "Facing an Uncertain Future;" the other reported last year as "Aggregates, Activities and Overheads," is in the final stages of revision. Gorman's paper explores, under very weak assumptions, the effect of separability in space and across states of nature in insuring that orderings can be represented by additive utility function.

FRANK H. HAHN

During the Summer of 1981, Frank Hahn developed earlier ideas on the nature of communication in the economic system and the responses of individual agents to conjectures about the behavior of others. He is applying them to the theory of inflation.

MORDECAI KURZ

Mordecai Kurz's work with the Center this year has been devoted to an exploratory evaluation of the effect of communication on the outcomes of noncooperative games. The topic of immediate interest is the process of coordination among participants. The motivating idea is that whereas uncertainty and incomplete information may make coordination difficult, there is also the possibility that the opposite effect may occur. The reason for this

effect is that the revelation of private information by a participant may occur indirectly by inference from his moves and may reveal as well something about his intentions or preferences. Thus strategic moves in the game have a signalling value and patterns of moves may acquire meaning as an endogenous language that facilitates coordination and ultimately other modes of communication. At this juncture the aim of Kurz's work is to characterize the Nash equilibria of such games in which the moves are not only payoff relevant but also have meaning as signals. Part of the work is aimed at establishing conditions sufficient to ensure incentive compatibility, namely no participant has an incentive to misrepresent.

ALAIN A. LEWIS

Alain Lewis's major project during his stay at the Center was to complete his exhaustive study of the theory of computability, via recursive methods, of rational choice functions. The main result, reported in two recent technical reports, is that even if a recursive representation exists for choice function whose domain includes subsets of a continuum, it may be recursively unsolvable. This result places an effective lower bound on the degree of computational complexity required to realize a rational choice procedure as a computational algorithm.

PAUL R. MILGROM

The Center's visiting Research Associate last year was Paul Milgrom. Part of his work on auctions, and on rational motives for cooperation is reported in the survey section of this Progress Report. He is also in the

process of finishing a joint paper with Robert Weber on auctions in which a series of identical items are sold sequentially one at a time. The chief theoretical result is that the sequence of prices should be a submartingale, and therefore tend upward in time as the auction progresses. This prediction is particularly interesting as a hypothesis that can be subjected to empirical testing using field data. While he was here he also completed revisions of six papers that are forthcoming in journals.

Milgrom's longer term project emanating from his stay here is a model of decentralization that follows on the Arrow and Radner paper on "Resource Allocation in Teams" but allows a much more complex structure of information. In particular, the distribution of subunits' (firms') characteristics in the population may be unknown and there may, a priori, be asymmetries among them. The principal result is a demonstration that in large economies or organizations, but not in small ones, the use of prices to allocate resources economizes on information gathering and communication costs.

HERVE MOULIN

During his tenure at the Center, Herve Moulin wrote about two-thirds of his new book, Game Theory for the Social Sciences, which has since been published by the Laboratoire d'Econometrie in Paris, and will receive an American publication by the New York University Press. The book is a comprehensive treatment of newer methods in game theory that are applied to the design of incentive-compatible and efficient processes of social choice. The book is especially notable for its treatment of the theory of self-enforcing agreements, and the analysis of consistent voting procedures.

ABRAHAM NEYMAN

Abraham Neyman spent the fall and winter jointly on the staff of the Center and in the Department of Economics. His Technical Report No. 366, "Semi-Values of Political Economic Games," characterizes all semi-values of a game which is the product of a "differentiable" non-atomic game with a weighted majority game, i.e., the payoff to a coalition is the product of a well-behaved payoff function with an indicator function which is 0 if the measure of the coalition is less than some critical value and 1 otherwise. (A semi-value is generalization of the Shapley value, satisfying less restrictive conditions.)

He also worked, jointly with Pradeep Dubey, of the Cowles Foundation for Research in Economics at Yale, on a paper, "Payoffs in Non-Atomic Games: An Axiomatic Approach." This has been distributed as Cowles Foundation Discussion Paper No. 610, with credit to the ONR contract supporting the Center. It was known that in the case of smooth, transferable utilities various solution concepts for the market coincide (e.g., the core, the competitive equilibrium, the value). Moreover, they consist of a single payoff. Their result gives an axiomatic foundation for this striking equivalence. They list four plausible axioms, anonymity, continuity, inessential economy, and separability, and prove that any solution concept that satisfies these four properties must be the coincident payoff of the different concepts listed above. This result could also be viewed asd a "meta-equivalence" theorem.

Neyman also started preparing two more papers, in collaboration with Leonard Mirman and Dov Samet, respectively. The paper with Mirman, "Diagonality of Cost Allocation Prices," sheds light on the striking phenomenon of

diagonality of various cost allocation prices, such as marginal cost prices and the so-called Aumann-Shapley prices; it is proved that every price mechanism (a correspondence from cost problems to prices, in which prices are defined only by cost conditions without reference to demand) that satisfy four simple axioms is necessarily diagonal, i.e., depends only on the production cost of those bundles of commodities that are almost proportional to the total consumption.

In the forthcoming paper with Samet, "The Existence and Uniqueness of the Value for Some Classes of Nonatomic Games," the existence and uniqueness of a continuous value is proved for various spaces of non-atomic games that include the games arising in the Aumann-Kurz models of power and taxes.

HERVE RAYNAUD

Herve Raynaud has been a regular visitor from the University of Grenoble. His work has dealt with value restriction conditions; these are a set of conditions on individual preference orderings which are, in a sense, necessary and sufficient for majority voting to be transitive. Essentially, the value restriction conditions say that for no three objects and no three individuals shall be there a cyclic set of orderings. Raynaud's two papers "How Restrictive Actually Are the Value Restriction Conditions," (T.R. 348) and "The Individual Freedom Allowed by the Value Restriction Condition," (T.R. 360), deal with the restrictiveness of the value restriction conditions; more precisely, he studies a quantity, $M(n)$, which is the maximum number of different preference orderings in a profile (set of preference orderings) on n object consistent with the value restriction conditions. In one paper, he

shows that $M(n) \leqq 2(n-1)!$, of the $n!$ possible orderings. In the second, he gives a very detailed combinatorial argument for the case $n = 4$, to show that $M(4) = 9$ but that the number of profiles which have 9 distinct order- ings of the 4 objects is only 24, a tiny fraction indeed of the more than 5 x 10^{11} possible profiles. Hence, the value restriction conditions are very restrictive indeed.

EYTAN SHESHINSKI

Eytan Sheshinski's recent work on the staff of the Center has been devoted to studies of firm's responses to inflation. Part of this work is reported in Technical Report 363, which studies how a firm adjusts its prices to cope with inflation that is uncertain, described as randomly spaced shocks each of which is identically distributed (i.e., a counting renewal process). The basic result is a certainty-equivalence result for the optimum policy of the (S,s) form: the firm behaves as if it faced with certainty a higher rate of inflation than the one actually observed, the difference being a risk premium that depends upon the interest rate. He is currently engaged in extensions to scalar Markovian stochastic processes, and to studies of the demand for money under stochastic inflationary conditions, including consum- ers' savings and consumption decisions.

This spring Sheshinski is in the early stages of work on firms' optimal structure of heirarchy when information is costly to transmit, following earlier work by Herbert Simon.

MICHAEL I. TAKSAR

Michael Taksar has been investigating models of centralized economies operating under uncertainty, and the design of optimal policies for prices and taxes. A technical report on this material is expected soon. His earlier work on a model of exploration of natural resources, treated as a diffusion process with an infinite rate of control, is nearing completion as well.

ROBERT WILSON

Robert Wilson's research during the past year is partially described in the main body of the Progress Report. These include the work preparing the paper on "Sequential Equilibrium" for publication; joint work with Kreps, Milgrom, and Roberts developing the results reported in the Technical Report on "Rational Cooperation in the Finitely Repeated Prisoners' Dilemma;" and preparation of the survey paper on "Perfect Equilibria and Sequential Rationality." In recent months considerable effort has been devoted to the construction of algorithms and computer routines to compute sequential equilibria of extensive-form games: although this effort is not immediately germane to the main objectives of the Center it is potentially quite useful in that it enables rapid computation of equilibria for the typical examples that are often studied in the theoretical work on games of incomplete information. Most recently, he has been studying the equilibrium strategies and efficiency properties of double auctions. Although this research is substantially complete it has not yet been prepared for publication as a Technical Report.

PROFESSIONAL ACTIVITIES

In September 1981 a conference was held at Luminy, France, on the subject of Games with Incomplete Information. This gathering of most of the principal researchers in this increasingly active field of study was sponsored by the French Mathematical Society and the National Center for Scientific Research. The topics covered the entire field, including both theoretical developments and the growing number of applications to traditional economic problems, as well as such related areas as sociobiology. Robert Wilson, Assistant Director of the Center, attended as a representative of the Center and presented a survey paper on "Perfect Equilibria and Sequential Rationality." This survey encompassed the earlier work on perfectness criteria in extensive-form games initiated by R. Selten and the recent work at the Center on the concept of a sequential equilibrium. Also in attendance and presenting papers were other members of the Center's staff not supported with travel funds: Robert Aumann, Mordecai Kurz, Paul Milgrom, Herve Moulin, and Abraham Neyman. A report on the conference was submitted to ONR immediately after the conference. Wilson's survey paper is available as an informal working paper of the Center.

Each summer the Institute for Mathematical Studies in the Social Sciences, the administrative home of the Center at Stanford, sponsors a two-month series of seminars on a broad range of topics at the forefront of research. In 1981 the Center played a supportive role in organizing and partially funding this series. The seminars provide a forum for reporting new research results and the proximity of many scholars with intersecting interests enables a stimulating collegial environment for joint work and exchanges of views.

In January 1982 the Center joined with IMSSS in partially supporting a small informal conference on recent developments in the theory of industrial organization. The conference, which proceeded without formal presentations of papers, was devoted to intensive discussions of basic conceptual issue and research strategies in this field which is now undergoing rapid change as the strategic approach is more widely adopted.

Kenneth Arrow's Presidential Address to the Western Economic Association in June 1981 appeared as T.R. 351 of the Center.

INSTITUTIONAL ACTIVITIES OF THE CENTER

A major role of the center is to promote and sustain a wide range of professional activities that contribute to research on organizational efficiency. The purpose of these activities is to stimulate scholars and practitioners from many fields of endeavor to appreciate the progress and challenges of this research area. The complex interdisciplinary character of the subject requires that criticism and contributions be obtained from several sources.

The chief modes of professional interchange are described briefly below:

Research Associates: The Senior Research Associates and Research Associates on the Center's staff are selected on the basis of outstanding contributions to research on topics connected with organizational efficiency. Most of these Associates reside at the Center for nine or twelve months. We are most fortunate to have assembled a distinguished group. Each depends upon the Center for a substantial part of his research support.

Visitors and Lecture Series: In the course of each year several prominent scholars are invited for short periods to participate in the Center's research programs. In each case a main event is the presentation of a public lecture on a topic in the visitor's field of study.

Interdisciplinary Seminar in Decision Analysis: This Seminar draws upon the diverse talents available at Stanford University both within and without the Center. The steering committee consists of Professors Arrow and Wilson and Professor Amos Tversky of the Department of Psychology. The topics concentrate on three areas: (1) empirical and theoretical studies of hypotheses about behavior under uncertainty alternative to the expected-utility hypothesis; (2) decision behavior in organizations; and (3) studies of

specific issues in actual decision-making, particularly those involving public policy.

The proceedings of these seminars, including papers or notes of the speakers, are published annually. The topics this year have been the following:

Date	Speaker	Title
October 13	Charles Plott	A Survey of Experimental Models in Political Economy Research
October 27	Charles Plott	Rational Expectations Models in Experimental Economics
November 10	John Kagel	Consistent and Inconsistent Choice Behavior of Pigeons and Rats
January 12	Vernon L. Smith	Theory and Behavior of Heterogeneous Risk Averse Bidders in a Multiple Unit Auction
January 26	Mordecai Kurz	Experiments in Income Maintenance
February 9	Dr. Joseph Newhouse	The Health Insurance Study
March 2	David Grether	Recent Experimental Evidence on Individual Decision-Making Under Uncertainty

Conferences: It is intended that the Center occasionally sponsor a major conference on a topic central to its research programs. Presently plans are being developed for a conference on the general subject of the Economics of Information. It is hoped that such conferences will succeed in convening the major contributors to the subject for a thorough assessment of the state of the field and its significance for practical affairs.

Publications: Part of the function of the Center's staff is preparation of expository reports in the areas of the Center's work. In addition to

technical reports of research accomplished by the staff, it is intended that the Center will publish reports on the field in general, designed to be useful to those involved in practical problems of evaluating and redesigning existing organizational arrangements. In addition, rapporteur's reports are prepared for the Center's various modes of professional activities. The three main report series are:

Technical Reports and Working Papers: These two series are intended for publication of completed research results, and preliminary results, respectively. Published articles are distributed as part of the Reprint Series. The Appendix lists those prepared during the current year.

Survey Papers: At infrequent intervals the Center will publish major surveys of important topics of practical interest. These are intended to cover broad fields of theory and practice, and to appeal to a wide audience. Kenneth Arrow is currently preparing surveys on two topics: "Information and the Market," and "The Theory of Social Choice."

Seminar and Lecture Reports: The Seminar reports prepared by the Center's staff include presently the papers presented and the discussions at the Seminar on Decision Analysis. Also to be included are the Lecture Series and the proceedings of conferences sponsored by the Center. As mentioned, plans are in a formative stage for a first conference on the Economics of Information; it is hoped that the Proceedings can be prepared in book form.

The Center will in the course of its normal procedures prepare periodic Progress Reports for the Office of Naval Research describing the Center's research accomplishments and summarizing its various activities. Copies of all publications will be transmitted to the Office of Naval Research.

Advice and Assistance: As part of its professional responsibility the Center stands ready to supply advice to the Office of Naval Research, and through it to other organizations, on the principles of evaluation and design of organizations and of information systems.

The research programs of the Center are intended to contribute broadly to studies of organizational efficiency. Among the topics to be investigated several are understood to be directly relevant to major areas of responsibility of the Office of Naval Research. These include (1) bidding, nonlinear pricing, and contracting; (2) design of efficient incentives; (3) economic analysis of information systems; (4) game-theoretic analysis of strategic behavior.

Publications of the Center will be forwarded to the Office of Naval Research, and at its discretion, made available for wider dissemination. In particular, the critical surveys of major topics provide comprehensive reviews of the state of knowledge in several areas of general importance to the research programs of the Office of Naval Research.

The several modes of professional interchanges that take place--including the Interdisciplinary Seminars, the Seminar and Lecture Series, and a major conference on the Economics of Information--will provide a valuable resource for those representatives of the ONR who choose to attend.

The Center welcomes the transmittal of comments about the choice and design of its research program, and of information about topics connected with the subject of organizational efficiency that may deserve intensive study.

STAFF AND VISITORS

STAFF:

KENNETH J. ARROW, Director

Joan Kenney Professor of Economics and Operations Research.

ROBERT B. WILSON, Assistant Director

Atholl McBean Professor of Decision Sciences in the Graduate School

of Business.

RESEARCH ASSOCIATES (1981-1982):

Mordecai Kurz, Director of Economics, Institute for Mathematical Studies

in the Social Sciences, and Professor of Economics.

Alain Lewis, Research Associate; visiting from the RAND Corporation.

Paul Milgrom, Research Associate; visiting from Northwestern University.

Abraham Neyman, Research Associate; visiting from Tel Aviv University.

Herve   Raynaud,   Research   Associate;   visiting   from   Laboratoire

D'Informatique et de Mathematiques Apliquees de Grenoble.

Eytan Sheshinski, Senior Research Associate; visiting from the Hebrew

University of Jerusalem.

Michael Taksar, Research Associate; Assistant Professor of Operations

Research.

APPENDIX

TECHNICAL REPORTS

T.R. No. 348. Herve J. P. Raynaud, "How Restrictive Actually Are the Value Restrictions Conditions," August 1981.

ABSTRACT

It has already been shown that the "value restriction conditions" are in a certain sense the best possible conditions ensuring the transitivity of the majority method of decision in Sen (to appear); nevertheless, the actual restriction demanded by these conditions has not been yet clearly measured.

In a previous paper on this subject we have shown that, if $n \geq 4$ is the number of alternatives and M_n the maximum number of different votes in a profile following the value restriction condition, then $M_4 = 9, M_5 \geq 21$ and in general $M_n > 2^{n-1}$. As $4! = 24$ and $5! = 120$, it is reasonable to conjecture that the ratio $M_n/n!$ (which can be considered as a measure of the amount of indiividual freedom which remains to an individual in a culture following a value restriction condition) tends to zero as n gets large.

T.R. No. 351. Kenneth J. Arrow, "Risk Perception in Psychology and Economics," October 1981.

ABSTRACT

The concept of rationality has been be ... to most economic analysis. Its content has been successively refined over the generations. As applied to the static world of certainty, it has turned out to be a weak hypothesis, not easily refuted and therefore not very useful as an explanation, though not

literally a tautology. But recent decades have seen the development of stronger versions applied to a world in which time and uncertainty are real. Among its most important manifestations have been criteria for consistency in allocation over time, the expected-utility hypothesis of behavior under uncertainty, and what may be termed the Bayesian hypothesis for learning, that is the consistent use of conditional probabilities for changing beliefs on the basis of new information. These hypotheses have been used widely in offering explanations of empirically-observed behavior, though, as not infrequently in economics, the theoretical development has gone much further than the empirical implementation. These hypotheses have also been used increasingly in normative analysis, as a component of benefit-cost studies (therefore frequently referred to as benefit-risk studies).

Hypotheses of rationality have been under attack for empirical falsity almost as long as they have been employed in economics. Herbert Simon and his colleagues have produced much evidence of the difficulties of human beings in arriving at rational choices even in rather simple contexts (for a survey, see Simon [1979]).

The rationality or irrationality of choice has become a leading interest of the branch of psychology called, "cognitive psychology." In good measure, the expected-utility hypothesis provided an important starting-point for these studies, in the sense that it provided a refutable hypothesis and indeed one for which the testing of implications was rather straightforward.

Recently, the controversy over nuclear power and its effects has sharpened interest in the way individuals form risk judgments and act on them. In particular, it has proved very difficult to reconcile changes in public

opinion attendant on new events with Bayesian learning models in any form. There has been renewed testing of expected-utility theory; one striking result has been the series of stunning experiments on the so-called "preference reversal" phenomenon by Lichtenstein and Slovic [1971].

A striking real life situation has given grounds for doubt as to the validity of the expected utility hypothesis. Since 1969, the United States government has offered flood insurance at rates which are well below their acturial value. Under the usual hypothesis of risk aversion, any individual should certainly be willing to take a favorable bet, even more because it offsets an otherwise fluctuating income. Yet until the government increased the pressure by various incentives, very few took out this insurance. A careful study by Kunreuther [1978] failed to uncover any reason consistent with the usual explanations of economic rationality.

Experiments and very special forms of insurance might be regarded as exceptions to an hypothesis which has turned out to be useful in more central features of economic life. Securities and futures markets might be taken as better exemplars. One standard implication of rationality which has been drawn repeatedly in current research, both empirical and theoretical, is that the price of a security or futures contract at any moment is an unbiased predictor of the price at a future moment, as adjusted for discounting and, possibly, uncertainty. This implies that the price change from the present to the future is uncorrelated with current price.

This argument presupposes that full use of available information, in this case an observed correlation presumably derived from past experience, is an aspect of rationality. It is assumed, then, that the rational individual will recognize any correlation to be found in the data.

Stewart's [1949] study of the grain futures market brought some rather discouraging evidence on this assertion. Non-professional speculators lost, especially surprising since they should be able to share with the professionals in receiving the net payments of the hedgers. In fact, they would have done better if, each time they decided to enter the market for a fixed commitment, they flipped a coin to determine whether to go long or short.

This observation certainly suggests an inability to recognize a rather simple empirical regularity, namely that outside speculators typically lose. Why did they enter the market at all?

In the securities and futures markets, there are typically arbitrage possibilities. That is, there are a set of connected markets which provide substitute outlets for purchase or sale. Since the holder is presumed to be interested solely in the money income (certain or uncertain) and not in the instrument from which it is derived, rationality has strong implications for the prices at which these instruments can sell. In the case of bonds, for example, under conditions of certainty about future short-term interests rates, the long-term interest rate must be effectively an average of them.

When participants in the securities or financial futures markets behave rationally, prices should change only when there is new information. The change in price from today to a future date, say one or two years off, will be the sum of a large number of daily changes, each reflecting new information as of that day. Rationally, it is clear from this that the change in any one day should be small, since it is merely one small piece of information among many. Hence, it seems intuitively clear that daily variations in the futures and securities markets are excessive relative to the daily changes in information.

Indeed, probability theory supplies necessary inequality relations among the variances of prices at different times or of prices in different markets related by arbitrage possibilities. There have been several studies suggesting that when tests of this general type applied to arbitrage situations, the proposed inequalities are violated. Especially noteworthy are Shiller's [1979, 1981] studies of the bond and stock markets. For example, in the bond market, the variability of long-term interest rates is too great to be explained as resulting from changing rational anticipations of future short-term rates.

I suggest that these failures of the rationality hypothesis are in fact compatible with some of the specific observations of cognitive psychologists. I am drawing especially on the work of Tversky and Kahneman [1974, 1981]. They and others have identified several heuristic devices by which individuals form cognitive judgements and note that, while each has useful properties, each can also lead to biases in judgement.

T.R. No 353. Paul Milgrom and John Roberts, "Predation, Reputation, and Entry Deterrence," November 1981.

ABSTRACT

Economists often argue that predatory practices are irrational, since there exist cheaper or more certain means to gain or maintain a monopoly. Our game-theoretic, equilibrium analysis suggests that if a firm is threatened by several potential entrants, then predation may be rational against early entrants, even if it is costly when viewed in isolation, because it yields a reputation which deters other entrants. Asymmetric information plays a

crucial role in our analysis, since it provides the rationale for entrants to base their expectations of the firm's future behavior on its past actions. The analysis also suggests methods to treat general reputational phenomena.

T.R. No. 355. Alain A. Lewis, "Recursive Rational Choice," November 1981.

ABSTRACT

The concept of a choice function, characterized by means of a set-valued mapping on restricted families of subsets of a space of alternatives is employed in an essential way in the theory of consumer choice in mathematical economics to construct demand correspondences (Mukherji [1977], Richter [1966], Sonnenschein [1971] and Uzawa [1956]). A concomitant consideration of such a function, arising out of Arrow's seminal considerations of social choice (Arrow, [1963]), is the extent to which a choice function may be considered rational. This problem has been treated extensively by Richter [1971]. However, a further consideration of rationality has been developed by Kramer [1974] in the consideration of whether or not a decisive choice function that is regular rational in the sense of Richter [1971] when defined on subsets of a denumerably infinite domain of alternatives, can be realized in principal by means of a device of artificial intelligence.

It is the purpose of the present study to indicate the means by which Kramer's results may be generalized to considerations of stronger computing devices than the finite state automata considered in Kramer's approach, and to domains of alternatives having the cardinality of the continuum. The means we employ in the approach makes use of the theory of recursive functions in the context of Church's Thesis. The result, which we consider as a preliminary

result to a more general research program, shows that a choice function that is rational in the sense of Richter (not necessarily regular) when defined on a restricted family of subsets of a continuum of alternatives, when recursively represented by a partial predicate on equivalence classes of approximations by rational numbers, is recursively unsolvable. By way of Church's Thesis, therefore, such a function cannot be realized by means of a very general class of effectively computable procedures. An additional consequence that can be derived from the result of recursive unsolvability of rational choice in this setting is the placement of a minimal bound on the amount of computational complexity entailed by effective realizations of rational choice. However, the principal interpretation of the result, in our present framework, is that a distinction must be placed between what is meant by a recursive representation of rational choice, and a recursive realization of that representation by effective computable procedures.

T.R. No. 358. Paul R. Milgrom and Robert J. Weber, "A Theory of Auctions and Competitive Bidding," December 1981.

ABSTRACT

The large volume of transactions arranged using auctions leads one to wonder what accounts for the popularity of such common auction forms as the English auction, the Dutch auction, the first-price sealed-bid auction, and the second-price sealed-bid auction. What determines which form will (or should) be used in any particular circumstance? Equally important, but less thoroughly explored, are questions about the relationship between auction theory and traditional competitive theory. One may ask: Do the prices which

arise from the common auction forms resemble competitive prices? Do they approach competitive prices when there are many buyers and sellers? In the case where the bidders may differ in their knowledge about the intrinsic qualities of the object being sold, do prices aggregate the diverse bits of information available to the many bidders (as they do in some rational expectations market equilibrium models)?

We review some important results of the received auction theory, introduce a new general auction model, and summarize the results of our analysis. We then present a formal statement of our model, and develop the properties of "affiliated" random variables. The various theorems are presented followed by our views on the current state of auction theory.

T.R. 359. William M. Gorman, "Facing an Uncertain Future," January 1982.

ABSTRACT

Economists often assume that organizations use criteria of the form

$$\sum_{t=0}^{T} c^t E[f(y_t)] \quad ,$$

in deciding on their actions, where $E(\cdot)$ is an expectations operator. If you like: that they seek to maximize the mathematical expectation of a discounted utility stream. This is a special case of an additive criterion

$$\sum_{s,t} f^{st}(y_{st}) \quad ,$$

where y_{st} is a vector of flows which occur in period t if state s obtains. The convenience of assuming these forms is clear. Is either

justified: they require, after all, that utility is additive over time, and over states, and that the same normalization does for each.

In many problems, all three of these results arise as the joint products of single arguments. This is because addition is, effectively, the only strictly increasing associative operation. Suppose for instance that

$$f(w,x,y,z) = d(w,\delta(x,y),z) = e[w,x,\varepsilon(y,z)] \quad,$$

where all functions are continuous, and strictly increasing in the subutilities, δ, ε. We then say that $X \times X$, $X \times Z$ are both separable, where X is the space of $x,\ldots$. This is possible iff

$$f(w,x,y,z) = g[w,a(x) + b(y) + c(z)]$$

where $g(\cdot)$ is continuous and $g(w,\cdot)$ is strictly increasing. The secret is the overlap between (x,y) and (y,z), or, better, between $X \times Y$ and $y \times Z$. To be able to tear y out of its association with x in $\delta(x,y)$, and put it in with z in $\varepsilon(y,z)$ instead, one effectively needs addition, or at least a strictly increasing transformation $g(w,\cdot)$ of it. What one wants to generate in a criterion like this is a considerable number of such overlaps. In this paper we develop the sufficient conditions for such a representation.

T.R. 360. Herve Raynaud, "The Individual Freedom Allowed by the Value Restriction Condition," January 1982.

ABSTRACT

It is known that the majority method (for an odd N, a is before b in the collective order iff more individual orders rank a before b than b

before a) does not always yield a total order. The frequency of the so-called "Condorcet effect" has been extensively derived and computed. K. Arrow, following the proof of his celebrated impossibility theorem, has given an example of possible escape by some "natural" restrictions on the domain of the individual orders. Since that time, various other conditions have been proposed. Then began to appear some sufficient and necessary "in a certain sense" conditions. The value restriction condition is among them. It seems to have a particular psychological interpretation which can justify a special treatment. In the case of total orders, the value restriction condition is equivalent to Ward's condition and can be written in the three following equivalent forms:

1. There is no $Y \subset X, |Y| \geq 3$, and no subset $(\theta_{i_1}, \dots, \theta_{i_{|Y|}})$ such that $\theta_{i_1}(Y), \dots, \theta_{i_{|Y|}}(Y)$ form the lines of a circulant matrix.

2. There is no Condorcet triple, i.e. there are no three objects (say, a,b,c) and no three individual orders such that their restrictions to the three considered objects constitute a cyclic triple (abc, bca, cab, or bac, acb, cba).

3. For every triple of objects, T, there is an object, say x, and a rank $j \in \{1,2,3\}$ such that in any $\theta_i(T)$, x is never ranked the j-th of the three objects in T.

This condition is necessary in the sense that it ensures the transitivity of the majority method for any odd subset of individual votes. Psychologically speaking one can understand that any profile with a cyclic triple can generate endless discussions between three voters, and endless hesitations when the voters are criteria in a decision making problem.

The third form will be used to study the condition, because it has appeared to be more tractable than the others. It is well known that when the number of objects increases, the frequency of cyclic triples increases very quickly, which means that satisfying the condition "per chance" becomes very unlikely.

The point of view retained here for enumeration is different. It focuses on the maximal number of different votes an individual can express. In other words, one will count the maximum number of different individual orders that can be found in a profile satisfying the condition.

T.R. 363. Eytan Sheshinski and Yoram Weiss, "Optimum Pricing Policy Under Stochastic Inflation," January 1982.

ABSTRACT

In this paper we consider pricing policies of individual firms in an inflationary environment. Each firm expects the general price level to increase and must determine the rate of increase of its own price. It is assumed that the firm incurs an adjustment cost when it changes its nominal price. Consequently, firms choose to change prices occasionally rather than continuously.

Our purpose is to analyze the dependence of the magnitude and the frequency of nominal price changes on the inflationary process. This problem has been analyzed by Sheshinski and Weiss (1977] and [1979] for the case of a fixed and certain rate of increase in the aggregate price level. This paper extends the analysis to the case of uncertainty.

The dependence of price policies of individual firms on the aggregate price level implies a relation between relative price dispersion and the inflation rate. This link is an important source of the real costs of inflation as pointed out by Okun [1971]. Extensive empirical research has established the existence of a positive relation between the rate of inflation and its variability and relative price dispersion (surveyed recently by Gordon [1981], Fischer [1981] and Taylor [1981]).

We consider an inflationary stochastic process in which the price level changes at intervals of random durations and at a magnitude which is also random. Each firm changes its nominal price whenever its real price falls below some predetermined level, s. The new nominal price is chosen to attain a predetermined real price, S. The duration of the period with fixed nominal price is thus random.

The main result of the paper is that for the class of stochastic processes with an exponential distribution of shock size, the optimal policy is the same as the one obtained under certainty for some specific rate of inflation. This certainty-equivalence rate of inflation always exceeds the expected rate of inflation by a risk premium which depends on the real interest rate and on the parameters of the stochastic process. One can therefore utilize results obtained by Sheshinski-Weiss [1977] for the certainty case to analyze the effects of changes in the parameters of the inflationary process. It is shown that a mean-preserving increase in spread leads to an increase in the amplitude of real price variations and decreases the expected frequency of nominal price changes. A spread-preserving increase in the expected rate of inflation increases the bounds within which real prices vary only if the variability of

expected future prices is small. Thus, the main empirical implication of Sheshinski-Weiss [1977] that a higher expected rate of inflation increases the amplitude of real price changes need not hold under more general circumstances.

T.R. 366. Abraham Neyman, "Semi-Values of Political Economic Games," February 1982.

ABSTRACT

Semi-values are defined in Dubey and Weber [1981] where characterization of the semi-values is given for two basic spaces; the space of all finite games, and the space of "differentiable" non-atomic games, i.e., pNA. In the purely economic situation, we usually encounter games in pNA (or in pNAD); but in many political economic situations, as in the Aumann-Kurz models of power and taxation [1977a], [1977b], we face games which are the products of weighted majority games by games in pNA. These games are members of other spaces which contain pNA and which we will refer to as spaces of political economic games. In this paper we will characterize all semi-values on spaces of political economic games. Section 3 presents a characterization of all continuous semi-values on a typical class of political economic games, followed by a detailed proof. In Section 4 we introduce further results without proofs. The proofs of the results in Section 4 are more involved than that of Section 3, but actually are based on the same ideas and thus we decided to omit them from our paper.

T.R. 367. Sergiu Hart, "Non-Zero-Sum Two-Person Repeated Games with Incomplete Information," February 1982.

ABSTRACT

An incomplete information environment is one where at least some of the participants do not possess all the relevant data. Much interest has been devoted in recent years to the analysis of such situations. In the economic theory literature, for example: the principal-agent problem; the theory of auctions; signalling (e.g., in insurance markets); rational expectations equilibria; and so on.

What are the main difficulties in such problems? First, consider the "informed" persons--those who know more than others. On one hand, it is to their advantage to make use of their additional information (in order to improve their own final outcome). On the other hand, by doing so they actually reveal this information--and their relative advantage vanishes. Thus--what is the good of being more informed, if one cannot profit from it? This type of conflict is an essential issue in the analysis of incomplete information environments.

The results of the analysis of such models of incomplete information usually indicate that some transmission of information does occur (possibly, in an implicit way only; namely, deducing information from actions taken by those possessing it). Thus, there is need for communications, and some sort of cooperation may arise (e.g., "trading information")--even though everything is based on purely selfish (non-cooperative) motives. There is yet another conflict--this time, for the "uninformed" participants. Should they trust the information transmitted by the informed ones?

Game theory is a tool for studying conflict situations--by definition, inter-personal conflicts. However, one obtains as an outcome resolution of intra-personal conflicts (like the ones mentioned above) as well--based on individual rational behaviour. This is true in particular for games with incomplete information--a class of which forms the subject of this paper.

An important development in game theory in recent years has been in the study of multi-stage games--especially, the so called repeated games, where the same game is played repeatedly. This suggests itself as a good framework for incomplete information games, for two main reasons.

The first one is that by its very nature, a repeated game has enough structure to allow the kinds of complicated behaviour we described above (and many others as well). There is enough "time" to enable players to "generate" certain beliefs in other people, or to make deductions, statistical infer-ences, and so on. There is also place for threats, for punishments--and for rewards too.

The second reason is more formal--although closely related to the first one. Consider an infinitely repeated game with complete information. A well known result (called the "Folk Theorem" since its authorship is not clear) states that the non-cooperative equilibria in the repeated game precisely correspond to the individually rational and jointly feasible points in the one-shot game. The importance of this result is that one obtains cooperative outcomes in the one-shot game from non-cooperative behaviour in the infinite game. Thus, the cooperation we usually observe is explained here not as an outcome of altruistic motives--but of purely selfish non-cooperative ones (which many feel are the only rational ones).

One is therefore led in a natural way to the study of _repeated games of incomplete information_. The first research on these was done in the Mathematica [1966-68] reports, in particular by Aumann, Maschler and Sterns. It turned out that the very complex structure of these games--which, as we pointed out above, is one of the reasons for studying them--creates many difficulties. Up to date, essentially only _two-person zero-sum_ games have been completely analyzed (see the forth coming book of Mertens and Zamir [1980], or the notes of Sorin [1980] for details).

As for the _non-zero-sum_ case (still, only _two players_), a first study has been done by Aumann, Maschler and Stearns [1968]. They characterized a special class of equilibria, in the so-called _standard one-sided information_ case, where one player has more information than the other one, and both observe during the play all the actions taken. These equilibria--called "enforceable joint plans"--essentially consist of a transmission of information from the informed to the uninformed player ("signalling"), followed by a completely non-revealing play from then on (similar to the Folk Theorem). Moreover, they showed that this does not exhaust all equilibria--one could have joint randomizations of enforceable joint plans, and so on.

Our main result in this paper is the _complete characterization of all equilibria_ in such games. We will show that every equilibrium is equivalent to a collection of non-revealing "plans," one of which is chosen at random. This choice is done via a sequence of communications, which are two types: signalling (i.e., implicit transmission of information), and jointly controlled randomizations (i.e., "lotteries" in which no one player can unilaterally change the probabilities.

Thus, we are able to characterize in a formal way all the kinds of cooperation and communication that arise out of non-cooperative behaviour in these games; moreover, we obtain a precise structure that guarantees it does not pay any player to do anything else (e.g., revealing less or more, or double-crossing, cheating, and so on). We would like to point out that the model is not the most general possible (in particular, in terms of the information structure); this paper is to be regarded as a first step in the analysis of non-zero-sum repeated games with incomplete information.

The formal model is described in Section 2, together with various notions of equilibrium. The main results are stated in Section 3, which also includes additional discussion and intuitive interpretations. Sections 4 and 5 are devoted to the two parts of the proof, and in Section 6 we present some results on enforceable joint plans. We would like to point out that Sorin [1981] has recently proved the existence of such equilibria whenever the number of possible games is two.

T.R. 369. Robert Kast, "Informational Equilibrium," January 1982.

ABSTRACT

This is a model in which agents make decisions and plan their future decisions using a signal and a forecast function. We define an informational equilibrium as a fixed point for forecasts and decisions: the distribution generated by the decisions matches the forecasts which help the decision making. How agents make their decision rationally, according to their forecast, has been studied elsewhere and we give two examples which fit our model. We focus on the relation, between decisions of agents and the distribution

they generate next period, through the structure of the model. We show that this relation is sufficiently continuous, so that an equilibrium will occur when agents decide continuously from their forecast. We use Probability transitions because they formalize forecasts, decision rules, Markov kernels of the process and postierior probabilities at the same time.

T.R. 371. Kenneth J. Arrow, "Team Theory and Decentralized Resource Allocation: An Example," February 1982.

ABSTRACT

The traditional discussion of the price system and alternative forms of decentralized resource allocation in organizations and entire economies has an ambivalent attitude to the ease of transferring information from one locus in the economic system to another. On the one hand, the very need for decentralization is based on the assumption that the transmission of information is costly. If this were not so, there would be no reason not to transfer all information on the availability of resources and the technology of production to one place and compute at one stroke the optimum allocation of resources. On the other hand, the literature has tended to seek algorithms which, in some sense, minimize the amount of information transferred but which at the same time yield in the end the fully optimal allocation of resources. In short, there is no true trade-off between information costs and other resource costs. If there were, one would expect that an optimal allocation of resources, taking account of information costs, would differ from the optimal allocation in the absence of information costs. The standard tradition can be rationalized only by assuming that information costs are infinitesimal but not zero;

hence, they should be minimized to the extent possible without affecting the overall allocation.

The theory of teams was introduced by Jacob Marschak precisely to bring information costs into the allocation process explicitly; see J. Marschak [1955], J. Marschak and Radner [1971]. It does so in a way which is polar to the standard tradition. It assumes a fixed amount of communication in fixed channels. The "costs" of communication are modelled by scarcity.

Team theory differs in other ways from the standard approach. It makes more use of prior information about the economy. In the usual form of the price-adjustment or quantity-adjustment iterative processes for achieving an optimal allocation of resources, the rule design uses only the broadest qualitative information about the economy. There are no assumptions about the likely shapes of the production functions or the range of possible levels of resource supplies. In team theory, some or all of the basic parameters of technology or resources are unknown; otherwise, there would be no informational problem at all. But there is prior information in the sense that probabilities are attached to different possible values of the parameters. The decisions made under decentralization can then take advantage of this knowledge and reduce the probabililty of a bad decision as far as possible.

There is still another difference between the standard approach and team theory, which follows from the fact that there are irreducible differences in information among the members of the team. In the standard approach, the decisions are ultimately all made by the central authority, the individual parts being only sources of information. In a sense, since relevant information is eventually equalized, it does not really matter who makes the

decisions. In team theory, as in real life, the allocations are ultimately the results of many individual decisions. The decentralization is real.

One implication among others is that the rules must be designed to insure feasibility without a full exchange of information on resource supplies.

The general form of the team problem, then, is this: The system has a number of agents, each charged with making certain decisions. The system's operations are governed by a number of parameters, initially unknown to the agents. There is a probability distribution over these parameters, reflecting prior knowledge. Each agent is given some information on some of the parameters. That is, the probabililty distribution of the parameters is conditioned on the agents' items of information. Each agent then makes a decision within its competence as a function of the information available to it. The team problem is to choose, in advance, the rules or decision functions for all agents. These decision functions are determined jointly to optimize the expected outcome, which is a function of the true values of the parameters and of the decisions made.

I will not try here to repeat in more detail the general formulation of the team problem, which can be found in J. Marschak and Radner [1972]. The structure will be sufficiently clear from the specific example to be analyzed. This example is very simple but requires sufficient analysis to indicate the nature of the team theory approach to resource allocation and the problems that need to be solved in applying it.

We assume a known production structure, indeed, the simple one of fixed coefficients. What are unknown a priori are the resource sup-plies. Each resource manager knows the supply of his or her own resource, and is required

to divide it between the general production using all supplies and a specialized alternative use. The paper is devoted primarily to establishing the decision rules for the resource managers which yield the optimal resource allocation for the given information structure.

A modification of the model would permit the resource manager to transmit incomplete information about resource holdings. In that case, the center, having received the information, would then issue decision rules to the resource managers. The extension is in fact very straight-forward. The calculation of the benefits from the additional information is straightforward in principle but does not lend itself to simple expression in formulas. These benefits should be compared with the costs of the additional information.

T.R. ____ (Reproduction in Process). Peter J. Coughlin and Melvin J. Hinich, "Necessary and Sufficient Conditions for Single-Peakedness Along a Linearly Ordered Set of Policy Alternatives," May 1982.

ABSTRACT

This paper studies societies which:

1. Select multidimensional economic policies through electoral competitions,

2. Have a linearly ordered set of predictive elements (such as an ideological continuum), and

3. Have economic decision makers.

It derives conditions which are both necessary and sufficient for such situations to always reduce to the familiar problem of a unidimensional election with single-peaked preferences (along this dimension). This leads to new median voter results. It also reveals certain important limitations on the